LBNE
Water System for Cherenkov Detector
Materials Compatibility and Water attenuation measurements

(LLNL Feb 10, 2011)

Lawrence Livermore National Laboratory

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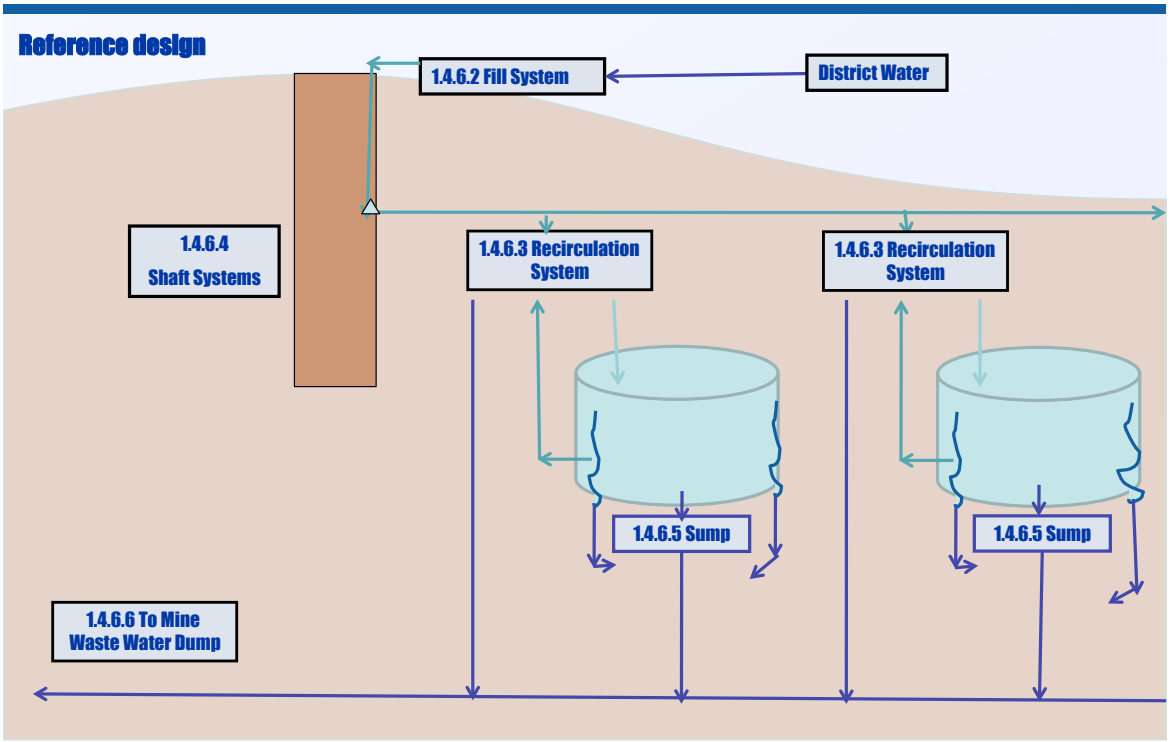
Outline

- Participation in LBNE
  - Status of engineering activities for LBNE
  - Physics motivation for gadolinium option
  - Non-proliferation motivation for gadolinium option
  - Water Attenuation Instrument at LLNL (DUSEL R&D)
    - Status of Deliverables
- Related Water detector development (ADG group)
- Proposed new work (DOE OS-HEP Proposal)
  - Materials compatibility with gadolinium doped water
  - LBNE water system engineering support

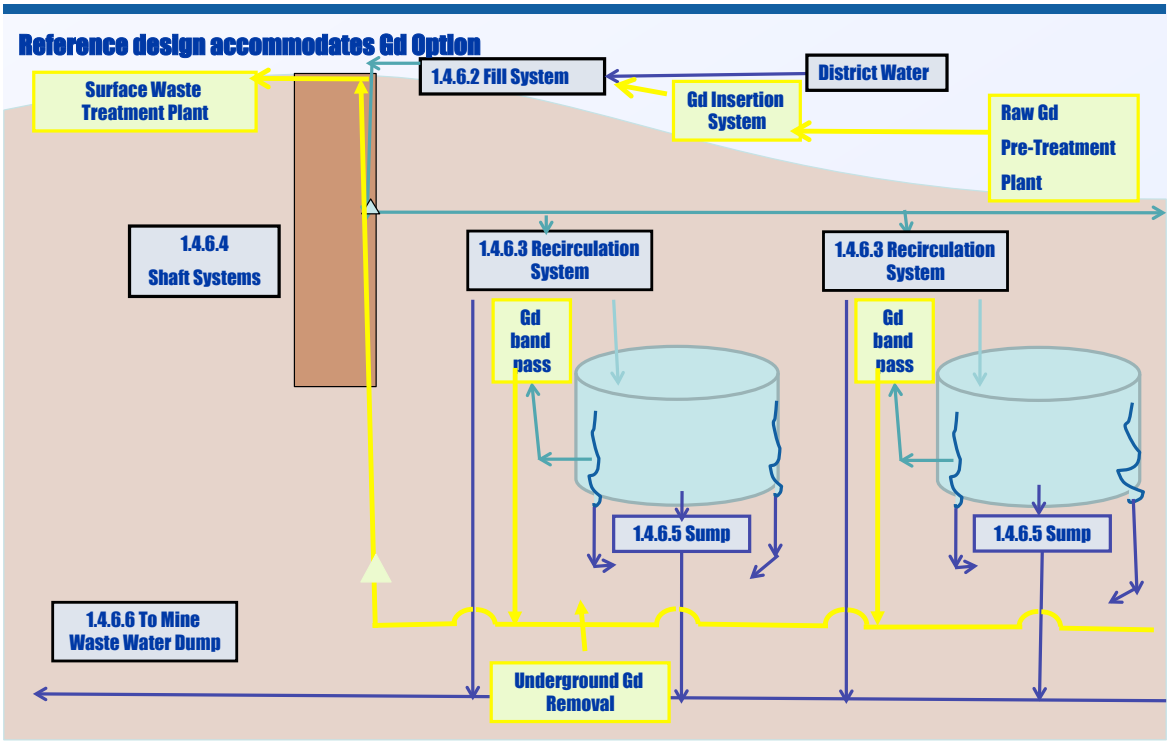
LBNE Water System Engineering (Direct LBNE funding)

- LLNL (Bionta) Leads 1.4 Water System
  - Project Engineer (Bahowick)
- UC Irvine (Sobel) Technical Lead
- @ LLNL developed WBS, Schedule, and Budget while preserving gadolinium option
  - Developed Water System Risk Registry
- LLNL has been asked to evaluate (Cost/benefit):
  - Reduce recirculation rate from 1200 gpm to 600 gpm
  - Relocate recirculation system at the surface
  - Use mine water to cool chiller
  - Relocate equipment off L5060 to L4850

Baseline (pure water) water system

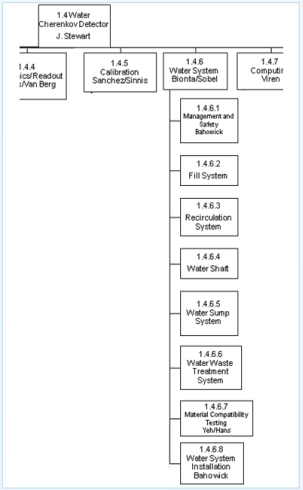


Gadolinium Option water system

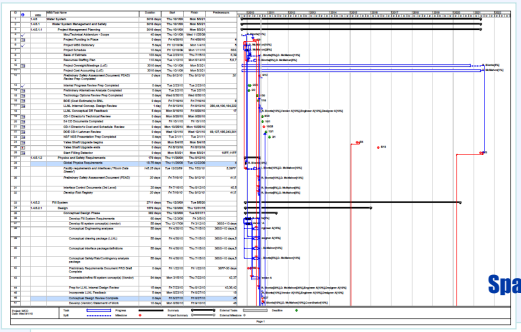


Water System Progress

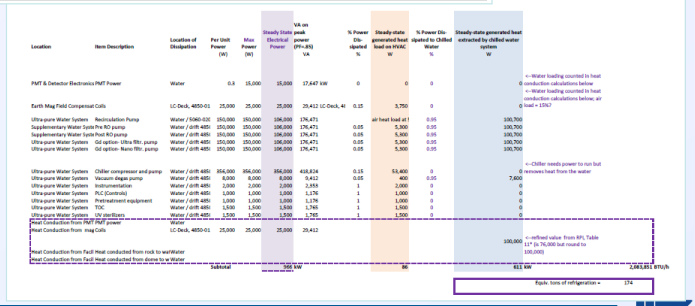
WBS



Schedule and Budget



Space and Power

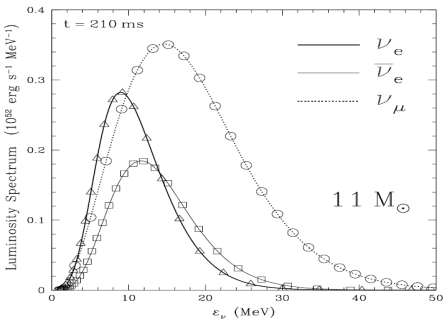


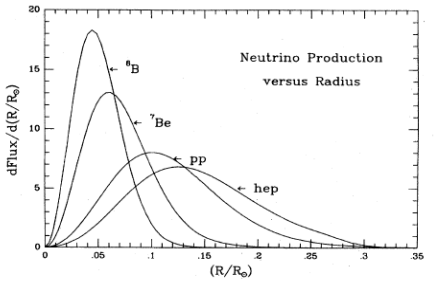
Physics motivation, 0.1 MT Water Cherenkov Detector with Gadolinium Option

•Gadolinium → antineutrino sensitivity

•Supernova Neutrinos
- •Time and Energy distributions of ν_e, $\bar{\nu}_e$, ν_μ, ν_τ constrain supernova hydrodynamics (need Gd)
- •Might observe Schirato-Fuller interactions of SN shock with neutrino mixing regions (need Gd)

•Solar Neutrinos
- •Observe hep ($^3He+p \rightarrow {}^4He+e^+ + \nu_e$) ν_es; map out solar temperature distribution from hep and ^8B neutrinos (the extremes in the distributions).





Physics motivation, ~1 MT Water Cherenkov Detector with Gadolinium Option

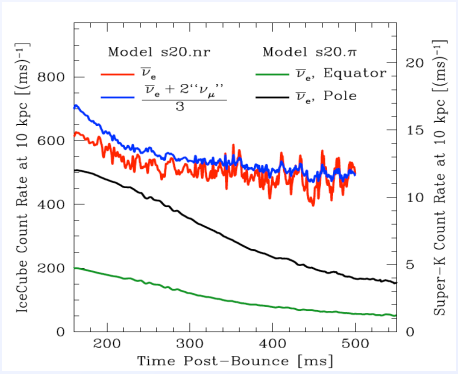
•How does the SN explode?
- •Perhaps from instabilities; they might leave an imprint on the neutrino yield via observable oscillations!

•Diffuse SN Neutrino Background
- •Yield best for massive (<40 solar mass) SN.
- •Would constrain theories of such stars.
- •Gadolinium would eliminate solar neutrino bkg., lower the detection threshold

•Gamma Ray Bursts:
- •Neutrinos could test basic understanding of short (neutron-star-black-hole merger; <1 s burst) and long (hypernovae; several s burst) time GRBs. (This would require a GRB in a nearby galaxy!)

•Advanced Stages of Stellar Evolution: Si burning
- •Would test impact of nuclear statistical equilibrium during silicon burning phase.
- •Would provide 1-2 day advance warning of a SN.

•Mixing from Cosmic Ray Neutrinos
- •Super-K and others observed mixing, but LSND and MiniBoone observed unexplained anomalies; need higher statistics data, and must distinguish between ν_e, and $\bar{\nu}_e$ (need Gd!)



T. Brandt et. al. 2010

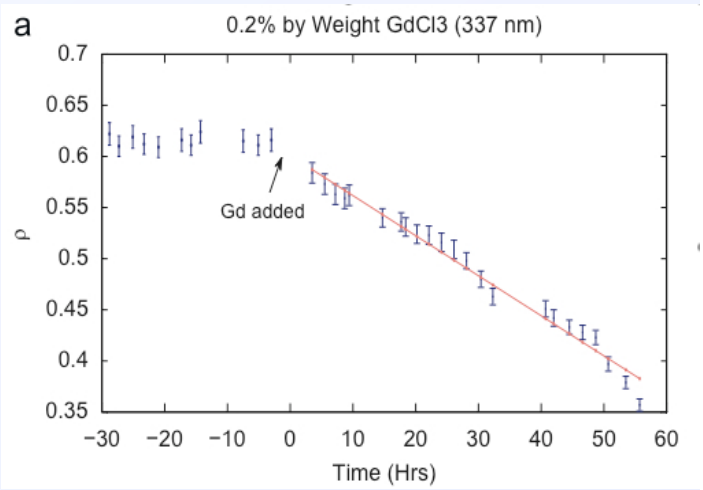
Non-Proliferation Motivation for gadolinium option @ LBNE

- Detection of anti-neutrinos (as demonstrated by KamLAND and SONGS) can be used to monitor reactors cooperatively (short baseline), or potentially out to ~500km radius (long baseline)
  - Water doped with a neutron capturing agent enables long baseline
  - Cost effective - enables large volume
  - May have medium baseline applications at surface

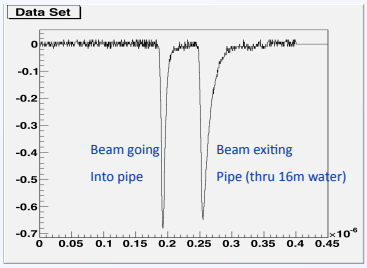
Prior work: Developed Relative Measurement of Water Attenuation (LLNL LDRD funded)

- $GdCl_3$ leaches iron from stainless steel, iron (at ppb level) destroys water clarity
- But does not immediately affect water quality
- Bottom line: $GdCl_3$ is not compatible with stainless detector components but Gd itself may be okay

see
W. Coleman et al. / Nuclear Instruments and Methods, A 595 (2008) 339–345



Recent work: Absolute attenuation length Measurement (DUSEL R&D)



Method:

Laser beam intensity is measured before and after transmission through attenuation arm filled with water sample. Both primary (P) and Reflected (R) beam intensities are measured with same PMT.

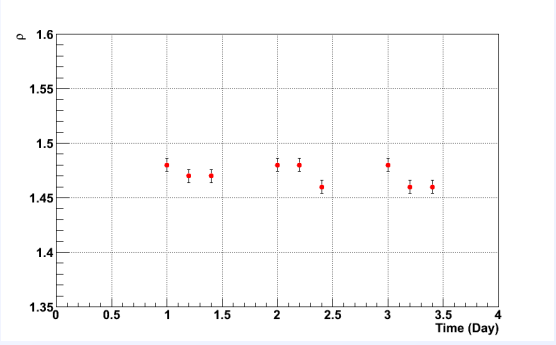
Measure ratio $\rho = R/P$ at 2 length scales (two pipes in same beam line), 16 meters and 0.5 meters

Assuming exponential attenuation, we get an absolute measurement

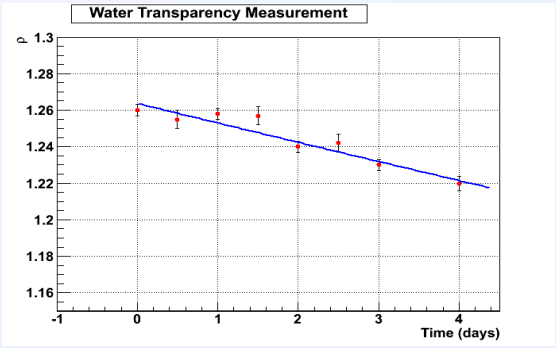
Attenuation effects @ unprecedented precision directly benefit LBNE

- LBNE needs to assess material compatibility – aim to reduce amount of water processing – saving $
- LBNE needs to know attenuation length to ~5% during the experiment (Energy scale)
- 5% changes in attenuation length @ the 100 meter level requires measurement uncertainty of ~1% to 1.5% over 16 meters (length of LLNL instrument)

Optical stability (No water in arm, ± 1.4%)



Optical stability (Pure DI water ± 1.5%)



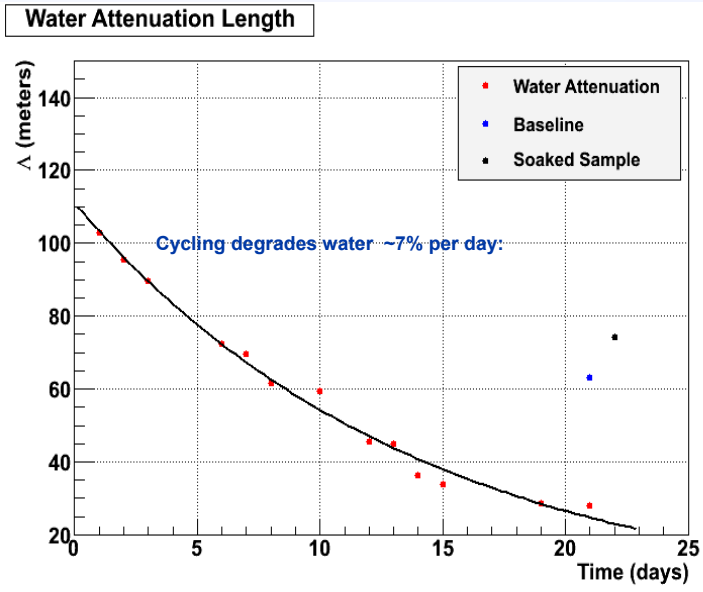
LLNL Attenuation Arm Long Term Stability Test

Three case studies over 21 days

Fill three 60 liter drums with purified water :

- Drum 1: transferred **daily** into instrument arm for transparency measurement and transferred back into the drum.
- Drum 2: Set aside as baseline. (The baseline sample.)
- Drum 3: Same as baseline **+** plastic liner candidate (GSE UltraFlex Smooth LLDPE) (The soak sample.)

Measured Attenuation Length in Pure water.



Attenuation Apparatus

➔Measurements repeatable to +/- 4% !! Best ever result at near UV!!

The measurement process produces some water degradation (as expected)

Baseline + soak daily degradation

~ 3% per day

Procedure is sensitive to drum cleaning

We believe the attenuation arm instrument produces stable measurements to within +/- 4%.

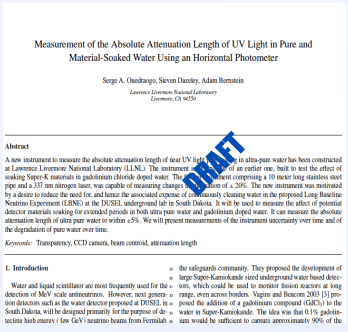
Q: How sensitive are our measurements to bottle cleaning procedures?

Date	Bottle#	Att. Length (Meters)
12/10/10	**A2**	**88.45**
01/03/11	A2	60.56
01/04/11	A3	59.40
01/05/11	A1	61.40
01/06/11	B1	69.37
01/07/11	B2	52.70

Differences seem to be due to drum cleaning (consulting with BNL)

Status of Deliverables (DOE OS DUSEL R&D)

- world class attenuation instrument completed
  - ~5% repeatability in near UV
  - Polypro + acrylic construction – benign to pure water
  - Design is of great interest to LBNE collaboration for use at the experiment
  - NIMA paper will appear shortly
  - Pure water soak tests have begun - #1 priority for LBNE


Measurement of the Absolute Attenuation Length of UV Light in Pure and Material-Soaked Water Using an Horizontal Photometer

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DRAFT

Abstract

A new instrument to measure the absolute attenuation length of near UV light in ultra-pure water has been constructed at Lawrence Livermore National Laboratory (LLNL). The instrument, a variant of an earlier one, built to test the effect of soaking Super-K materials in gadolinium chloride doped water. The instrument comprising a 10 meter long stainless steel pipe and a 337 nm nitrogen laser, was capable of measuring changes in attenuation of ± 20%. The new instrument was motivated by a desire to reduce the need for, and hence the associated expense of continuously cleaning water in the proposed Long Baseline Neutrino Experiment (LBNE) at the DUSEL underground lab in South Dakota. It will be used to measure the affect of potential detector materials soaking for extended periods in both ultra pure water and gadolinium doped water. It can measure the absolute attenuation length of ultra pure water to within ±5%. We will present measurements of the instrument uncertainty over time and of the degradation of pure water over time.

Keywords: Transparency, CCD camera, beam centroid, attenuation length

1. Introduction

Water and liquid scintillator are most frequently used for the detection of MeV scale antineutrinos. However, next generation detectors such as the water detector proposed at DUSEL in South Dakota, will be designed primarily for the purpose of detecting high energy (few GeV) neutrino beams from Fermilab ... the safeguards community. They proposed the development of large Super-Kamiokande sized underground water based detectors, which could be used to monitor fission reactors at long range, even across borders. Vagins and Beacom 2003 [3] proposed the addition of a gadolinium compound ($GdCl_3$) to the water in Super-Kamiokande. The idea was that 0.1% gadolinium would be sufficient to capture approximately 90% of the

- Gadolinium sulphate is now preferred neutron capturing agent, $GdCl_3$ is ruled out for now
  - Water can be actively cleaned (UCI work – Vagins et. al.)
  - No gadolinium sulphate soak tests have been done (by anyone in LBNE) so far. THIS NEEDS TO BE DONE SOON

ADG Group Expertise

4 years developing our “Best in Class” Attenuation measurement device

Relevant experience

3 large water based gadolinium doped antineutrino and neutron detectors @ LLNL

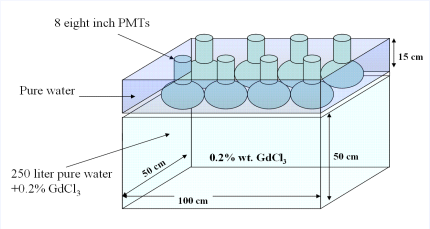
20 person years experience at KamLAND and at SONGS (non-proliferation applications)

Additional multi-year experience at Double Chooz, Super-K and MiniBoone

Current water based neutron/antineutrino detectors @ LLNL

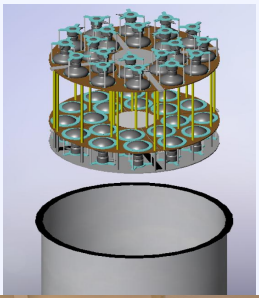
Funded through DOE NA-22

1) 250 liter antineutrino/neutron detector, proof of principle

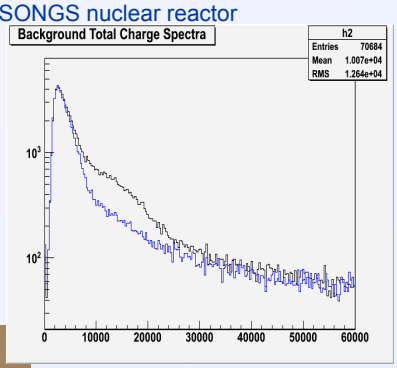


First published results showing
Neutron detection with
Gd Water detector
Dazeley et. al. Vol 607, P619, 2009

3) 4 ton neutron detector



2) 1 ton water/$GdCl_3$ antineutrino detector, currently deployed at SONGS nuclear reactor



Conclusion

Present work: (funded under direct LBNE funding)

Water System Engineering

1) WBS, schedule, budget for Water system + preserving gadolinium option

2) Value Engineering studies

3) CD1 preparation work

We may submit a proposal to DOE OS for continued engineering studies if LBNE funding is delayed

Water Attenuation R&D for LBNE

1) we are now testing repeatable bottle cleaning procedures in detail. Turns out this is not trivial

2) perform long term soak tests of LBNE detector materials in pure **UNDOPED** water

Proposed work: (DOE OS - HEP)

LBNE needs long term soak tests of material compatibility with gadolinium sulphate as soon as possible to preserve the gadolinium option.

The LBNE instrument is accurate (repeatable) to within 4% in near UV (337nm) Best available!

We are requesting support for gadolinium sulphate material compatibility measurements

(½ a postdoc over two years + gadolinium sulphate processing equipment, blue laser + consumables)